CLAIMS

1. A projection optical system for projecting an image of a first plane (OP) onto a second plane (IP) comprising:

a boundary lens (E233); and

at least one layer of immersion liquid (IL) between the boundary lens (E233) and the second plane (IP);

said boundary lens (E233) having a first plane side optical surface (S263) shaped such that for light projected onto the second plane (IP) through the boundary lens (E233) the marginal ray convergence angle (L) prior to incidence is larger than the marginal ray convergence angle (S) within said boundary lens (E233).

2. The projection optical system of Claim 1 further comprising:

at least one positive powered lens element (E231, E232) proximal to said boundary lens (E233), and having an aspheric optical surface (S259, S260, S261, S262).

3. The projection optical system of Claim 1 wherein there are provided:

a first positive powered lens element (E231) proximal to said boundary lens (E233), and having at least one aspheric optical surface (S259, S260); and

a second positive powered lens element (E232) between the first positive powered lens element (E231)

and said boundary lens (E233), and having at least one aspheric optical surface (S261, S262).

4. The projection optical system of any one of Claims 1 to 3 further comprising a double-Gauss anastigmat arranged to reduce spherical aberration including a third positive powered lens element (E222), a first negative powered lens element (E223), a second negative powered lens element (E224), and a fourth positive powered lens element (E225).

5. The projection optical system of any one of Claims 1 to 4 further comprising a catadioptric anastigmat comprising a concave mirror (E215) and at least one negative powered Schupmann lens (E213, E214).

6. The projection optical system of Claim 5 wherein the catadioptric anastigmat comprises two negative powered Schupmann lenses (E213, E214).

7. The projection optical system of any one of Claims 1 to 6 adapted for use with ultraviolet light.

8. A projection optical system for projecting an image of a first plane (OP) to a second plane (IP) comprising:

an optical system;

a boundary lens (E233); and

at least one layer of immersion liquid (IL) between said boundary lens (E233) and said second plane (IP); wherein

light from the first plane (OP) is transmitted through the optical system, and output with a predetermined marginal ray convergence angle (L); and

said boundary lens (E233) is positioned to receive said light output from the optical system, and adapted such that for light projected onto the second plane (IP) through the boundary lens (E233) the marginal ray convergence angle (L) prior to incidence is larger than the marginal ray convergence angle (S) within said boundary lens (E233).

9. The projection optical system according to Claim 8 wherein the optical system comprises:

at least one positive powered lens element (E231, E232) proximal to said boundary lens (E233), and having an aspheric optical surface (S259, S260, S261, S262).

10. The projection optical system of Claim 8 wherein the optical system comprises:

a first positive powered lens element (E231) proximal to said boundary lens (E233), and having at least one aspheric optical surface (S259, S260); and

a second positive powered lens element (E232) between the first positive powered lens element (E231) and said boundary lens (E233), and having at least one aspheric optical surface (S261, S262).

11. The projection optical system of any one of Claims 8 to 10 wherein the optical system comprises:

a double-Gauss anastigmat arranged to reduce spherical aberration including a third positive powered lens element (E222), a first negative powered lens element (E223), a second negative powered lens element (E224), and a fourth positive powered lens element (E225).

12. The projection optical system of any one of Claims 8 to 11 wherein the optical system further comprises a catadioptric anastigmat comprising a concave mirror (E215) and at least one negative powered Schupmann lens (E213, E214).

13. The projection optical system of Claim 12 wherein the catadioptric anastigmat comprises two negative powered Schupmann lenses (E213, E214).

14. The projection optical system of any one of Claims 8 to 13 adapted for use with ultraviolet light.

15. A method of projecting an image of a first plane onto a second plane (IP) including the steps of:

passing light having a first marginal ray convergence angle (L) to a boundary lens (E233);

passing light having a second marginal ray convergence angle (S) though the boundary lens (E233); and

passing light from said boundary lens (E233) through a layer of immersion liquid (IL) to the second plane (IP); wherein

the first marginal ray convergence angle (L) is greater than the second marginal ray convergence angle (S).

16. The projection method of Claim 15 including the step of passing light through at least one positive powered lens element (E231, E232) proximal to said boundary lens (E233), and having an aspheric optical surface (S259, S260, S261, S262).

17. The projection method of Claim 15 including the steps of:

passing light through a first positive powered lens element (E231) proximal to said boundary lens (E233), and having at least one aspheric optical surface (S259, S260); and

passing light through a second positive powered lens element (E232) between the first positive powered lens element (E231) and said boundary lens (E233), and having at least one aspheric optical surface (S261, S262).

18. The projection method of any one of Claims 15 to 17 further including the step of passing light through a double-Gauss anastigmat arranged to reduce spherical aberration including a third positive powered lens element (E222), a first negative powered lens element (E223), a second negative powered lens element (E224), and a fourth positive powered lens element (E225).

19. The projection method of any one of Claims 15 to 18 including the step of passing light through a catadioptric anastigmat comprising a concave mirror (E215) and at least one negative powered Schupmann lens (E213, E214).

20. The projection method of Claim 19 including the step of passing light through two negative powered Schupmann lenses (E213, E214).

21. The projection method of any one of Claims 15 to 20 wherein said light is a beam of ultraviolet light.

22. An exposure apparatus comprising an illuminating system for illuminating a mask set on the first plane (OP), and a projection optical system according to any one of Claims 1 to 21 for forming an image of a pattern formed on said mask on a photosensitive substrate set on the second plane (IP).

23. An exposing method comprising the steps of illuminating a mask set on the first plane (OP), and projecting and exposing a pattern image formed on said mask on a photosensitive substrate set on the second plane (IP) via the projection optical system according to any one of Claims 1 to 21.

24. A projection optical system for projecting an image of a first plane (OP) onto a second plane (IP), comprising:

an optical path having a plurality of lenses including a boundary lens which is arranged at a position closest to the second plane, wherein the first plane (OP) side surface of the boundary lens has a positive refractive power, and for an atmosphere in said optical path having a refractive index of 1, the optical path between said boundary lens and said second plane (IP) is filled with a medium having a refractive index larger than 1.1.

25. The projection optical system according to Claim 24, which satisfies the condition as expressed by:

$$0.012 < Cb \cdot D/NA < 0.475$$

where, Cb represents the curvature of said boundary lens on the first plane (OP) side; D represents the distance between an optical axis and the outermost point of an effective image forming area, and NA represents the numerical aperture on the second plane (IP) side of the boundary lens.

26. The projection optical system according to Claim 24 or 25, wherein at least one optical member (Lp) having substantially no refractive power is arranged in the optical path between said boundary lens and said second plane (IP); and the optical path between said boundary lens and said optical member, and the optical path between said optical member and said second plane (IP) are filled with said medium.

27. The projection optical system according to Claim 26, wherein said at least one optical member having substantially no refractive power is detachably arranged in the optical path between said boundary lens and said second plane (IP).

28. The projection optical system according to Claim 26 or 27, wherein the optical member having substantially no refractive power has an adjustable orientation.

29. The projection optical system according to any one of Claims 26 to 28, wherein said projection optical system satisfies the condition as expressed by:

$$|P \cdot D| < 1.0 \times 10^{-4}$$

where, P represents the refractive power of said optical member having substantially no refractive power, and D represents the distance between the optical axis and the outermost point of the effective image forming area.

30. The projection optical system according to any one of Claims 24 to 29, wherein said projection optical system is a catadioptric optical system comprising at least one concave reflector.

31. The projection optical system according to Claim 30, having an effective image forming area eccentric relative to the optical axis, wherein at least one

intermediate image is formed in said optical path of said projection optical system.

32. The projection optical system according to Claim 31, comprising one image forming optical system (G2), having said at least one concave reflector, for forming said intermediate image; and another image forming optical system (G3) for forming a final image on said second plane (IP) on the basis of the flux from said the intermediate image; and

a deflecting mirror arranged in the optical path between said one image forming optical system and said another image forming optical system.

33. The projection optical system according to Claims 32, wherein the following conditional expression is satisfied:

$$0.75 < MA/MG3 < 1.1$$

where, MA denotes a magnification of the whole optical system, and MG3 denotes a magnification of the another imaging optical system (G3).

34. The projection optical system according to Claim 31, comprising a first image forming optical system (G1) for forming a first intermediate image of said first plane (OP); a second image forming optical system (G2), having said at least one concave reflector, for forming a second intermediate image on the basis of said first intermediate image; and a third image

forming optical system (G3) for forming a final image on said second plane (IP) on the basis of the flux from said second intermediate image; wherein:

a first deflecting mirror is arranged in the optical path between said first image forming optical system and said second image forming optical system; and a second deflecting mirror is arranged in an optical path between said second image forming optical system and said third image forming optical system.

35. The projection optical system according to Claim 34, wherein the optical axis of said first image forming optical system is aligned with the optical axis of said third image forming optical system.

36. The projection optical system according to Claim 34 or 35, wherein the following conditional expression is satisfied;

$$0.75 < MA/MG3 < 1.1$$

where, MA denotes a magnification of the whole optical system, and MG3 denotes a magnification of the third imaging forming optical system (G3).

37. The projection optical system according to Claims 32 or, wherein said another image forming optical system (G3) includes an aperture stop, and wherein the number of lens elements arranged on the second plane (IP) side of the aperture stop is five or less.

38. The projection optical system according to Claims 37, wherein all lens elements arranged between the second plane (IP) and the aperture stop in the third image forming optical system have positive refractive power.

39. The projection optical system according to Claims 37, wherein no lens element having negative refractive power is included in the lens elements arranged in the second plane (IP) side of the aperture stop.

40. The projection optical system according to any one of Claims 24 to 39, wherein the numerical aperture on the first plane (OP) side is 0.22 or larger.

41. The projection optical system according to any one of Claims 24 to 40, wherein the light quantity loss occurring upon passing through said medium is 50% or lower.

42. An exposure apparatus comprising an illuminating system for illuminating a mask set on a first plane (OP), and a projection optical system according to any one of Claims 24 to 41 for forming an image of a pattern formed on said mask on a photosensitive substrate set on said second plane (IP).

43. An exposing method comprising the steps of illuminating a mask set on a first plane (OP), and projecting and exposing a pattern image formed on said mask on a photosensitive substrate set on a second

plane (IP) via the projection optical system according to any one of Claims 24 to 41.